

A Novel Program-Erasable High- κ AlN Capacitor with Memory Function

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Abstract

One of the most difficult challenges for Flash memory is how to scale down the tunnel oxide thickness that is limited by the stress-induced leakage current generated oxide traps. Although SONOS memory can improve the data loss by using discrete quantum traps, relatively thick tunnel oxide is still required to confine the injected and trapped electrons in nitride. Another difficult challenge for Flash or SONOS memory is the very thick oxide/[poly-Si or SiN]/oxide dielectric that is incomparable to CMOS technology with ultra-thin dielectric and equivalent-oxide thickness (EOT) of <1.2 nm. However, the integration of non-volatile memory into CMOS is the technology trend to realize the multi-function SoC.

In this paper, we propose and demonstrate an alternative solution using the high- κ [1]–[2] AlN capacitor for 1T1C non-volatile memory similar to ferroelectric RAM (FRAM). This novel high density ($5\text{fF}/\mu\text{m}^2$) AlN capacitor can be programmed and erased at voltages of +4 and -4 V for ≤ 1 ms respectively, which may be due to the charge trapping or de-trapping in the high trap density AlN. Reasonable good data retention occurs with a threshold voltage change of only 0.06 V after +4 or -4 V program or erase for 10^4 sec, which is already useful for SDRAM application and much better than the volatile DRAM. The almost symmetrical threshold voltage to 0V for program and erase is important for low voltage applications. Although the charge trapping mechanism is similar to SONOS memory [3], the erase mechanism in single layer AlN is fundamentally different from the multi-layer SONOS. It is important to notice that the erase function does not exist in high- κ Al_2O_3 , AlON or other known single high- κ layer [1]–[2] capacitors where continuous increasing threshold voltage is measured even at very high voltage of -10 V.

We have also investigated the device characteristics of a 3nm- LaAlO_3 /7nm-AlN/3nm- LaAlO_3 MONOS capacitor, in order to understand the unique erase mechanism in the single layer 16nm-AlN capacitor. Because the LaAlO_3 has a very high- κ of 25, the high capacitor density and drive current can still be preserved. Although similar erase function and retention characteristics are measured, a 3.5X higher electric field is required than single layer AlN device. In addition, higher erase voltage of -6 V is required and the threshold voltage no longer symmetrical to 0 V but shifts to negative voltage. These results suggest the high- κ AlN trapping/de-trapping layer is the main electron storage layer and the additional 3nm- LaAlO_3 tunnel oxide may block the erase function in MONOS memory. Therefore, possible reasons for the erase function may be the smaller energy bandgap or valence band discontinuity ΔE_V than Al_2O_3 or Si_3N_4 used in SONOS, which allows hole injection or electron tunneling involving high-density trap states.

Because the high- κ AlN dielectric was deposited on Si and processed at a max temperature of only 400°C, this device can be integrated into VLSI backend similar to analog and RF capacitor [4]–[5]. Therefore, this device has the merits of fully process compatible to current VLSI. Besides, the 1T1C approach can be embedded in current VLSI and utilize the advantage of fast scaling of CMOS technology without facing difficult challenge of scaling issue in Flash memory.

In summary, we have demonstrated for the first time a program and erasable single-layer memory capacitor with reasonable good retention using the unique property of high- κ AlN dielectric.

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